

FP7 E³ PROJECT KEY CHALLENGES

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ABSTRACT

This paper presents the ambitions and objectives of the FP7 End-to-End Efficiency (E³) project proposal. Building on the outcomes of the FP6 End-to-End Reconfiguration (IST-E²R) project [1], E³ is aiming at integrating cognitive wireless systems in the Beyond 3G (B3G) world, evolving current heterogeneous wireless system infrastructures into an integrated, scalable and efficiently managed B3G cognitive system framework from a technical, regulatory and business perspective. The cohabitation of multiple heterogeneous Radio Access Technologies (RAT) is studied with the objective to provide system design and management solutions based on Cognitive System principles; in this context, collaborative and autonomous decision making approaches are considered from both, the network and user terminal point of view. Additionally, related enabling technologies are developed, such as the Cognitive Pilot Channel. The prototyping effort will showcase the efficiency of the proposed solutions in a multi-technology environment.

1. INTRODUCTION

The End-to-End Efficiency (E³) consortium has proposed an ambitious FP7 [2] EC Large Scale Integrating Project (IP) proposal aiming at integrating cognitive wireless systems in the Beyond 3G (B3G) world, evolving current heterogeneous wireless system infrastructures into an integrated, scalable and efficiently managed B3G cognitive system framework. The key objective of the E³ project is to design, develop, prototype and showcase solutions to guarantee interoperability, flexibility and scalability between existing legacy and future wireless systems, manage the overall system complexity, and ensure convergence across access technologies, business domains, regulatory domains and geographical regions.

E³ will make converge both cognitive radios and cognitive networks from technical, business, regulatory and standardisation perspectives. E³ will build on the IST-E²R research results on reconfigurable equipment extending the corresponding concepts towards the design of a wireless cognitive radio system in which network entities will be able to self-adapt to a dynamically changing context (i.e., user traffic demands, etc.). The focus will furthermore be on the evolution of wireless systems in an evolutionary, non-disruptive way, by integrating existing wireless radio standards into a common framework with user devices be able to reconfigure and maintain one or multiple links simultaneously, and contributing to currently active/emerging standardisation bodies with a focus on key convergence enablers. In particular, ongoing standardisation on IMT-Advanced related radio and cognitive systems are targeted, with contributions enabling the convergence towards a future harmonised and interoperable wireless landscape. E³ will devise structuring rules for the definition and design of next generation of various standards (e.g. IEEE 802.16/11, IEEE P1900 [2], ETSI, 3GPP....) allowing a seamless use of these standards to fulfil the scenarios of the current definitions of 4G systems at lower cost and complexity, and for a better spectrum efficiency (plug and play “lego blocks” for standards).

A key effort will be laid on the efficient distribution of decision making mechanisms over the system entities, either based on collaborative or on fully autonomous decision making principles.

This paper will give an overview of the global vision as well as the key technical axes of the project and is organized as follows. Chapter 2 presents the global vision of the E³ system approach, followed by a detailed presentation of the key project axes. Chapter 4 details the related standardization and regulation strategy and Chapter 5 finally gives a conclusion.

2. E³ SYSTEM VISION AND APPROACH

The E³ vision of the future framework, consisting of a multitude of heterogeneous standards, building on CR/CN principles is presented in Figure 2: several operators are supposed to be present, each controlling multiple Air Interfaces, such as cellular (UMTS, HSDPA and LTE, a future 4G, etc.), metropolitan area (WiMAX, next generation WiMAX based on IEEE 802.16m, etc.), short-range (WiFi systems based on IEEE 802.11a/b/g/e/etc., next generation WiFi systems based on IEEE 802.11n, etc.). In this context, mobile terminals are expected to have the possibility of maintain links to one or several of the air interfaces simultaneously. The corresponding decision making tasks are distributed over the Network Reconfiguration Management entity on the network side and the Terminal Reconfiguration Management entity on the terminal side, relying on the Cognitive Pilot Channel in order to exchange the related information.

The ability of maintaining multiple links simultaneously is a key element of E³'s strategy to enable a gradual, non-disruptive evolution of existing legacy standards towards a novel system concept (e.g., IMT-Advanced) providing high throughput, better availability, more advanced services, etc. In this perspective, multiple simultaneous links will enable user terminals to increase the respective throughput; the split of data streams over multiple air-interfaces will enable the exploitation of an additional system diversity where some Radio Access Technologies (RATs) are providing very high throughput, but at a limited availability while other RATs will provide lower throughput, but at a very large coverage area and at a high-level of availability, etc.

The **main challenges of E³** will be to develop and showcase knowledge related to cognitive B3G convergence beyond state-of-the-art and contribute to the development, regulation and standardisation of the corresponding system following an End-to-End approach: aspects ranging from the access and backbone network, over corresponding cognitive enablers such as a cognitive pilot channel, to the terminal side are studied from an economic, regulatory and technical viewpoint. In this framework, the related studies will focus on the following main objectives:

- **Design of a Cognitive Radio System exploiting the capabilities of reconfigurable networks and self-adaptation to a dynamically changing environment.** In order to minimise the reconfiguration overhead, to maximise the reactivity of network entities to any context change in a dynamic scenario and to control the calculation complexity distribution, both, edges of the network and user devices are fed with context information by suitable enablers which are introduced in the project, such as a physical and/or logical Cognitive Pilot Channel, etc. Based on this knowledge, the network entities are performing the link optimisation in a distributed way – either fully autonomously or subject to network constraints which may be imposed in a collaborative optimisation process with the goal to improve the reliability and convergence characteristics.
- **Enable a gradual, non-disruptive evolution of existing wireless networks in accordance to user requirements.** In particular, the system capacity and QoS provision is updated based on a by-need basis building on an existing deployment.

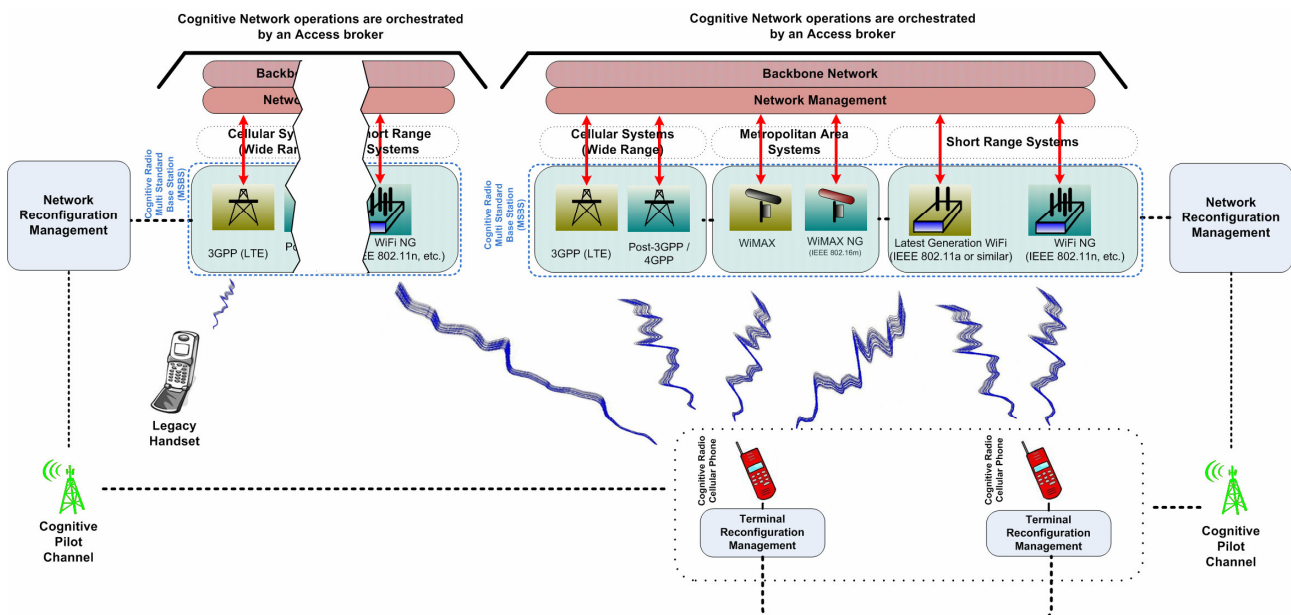


Figure 1: The E³ System Vision.

The vision of ubiquitous high-speed networks is possible to become reality in a short- to mid-term perspective by exploitation of simultaneous legacy Radio Access Technology (RAT) links in mobile terminals. This approach will then be enriched by future ultra-high throughput standards, representing new bricks in the heterogeneous landscape,

- **Define means to increase the efficiency of wireless network operations, in particular by optimally exploiting the full diversity of the heterogeneous radio eco-space**, both from the operators and users perspectives: in order to ensure flexible and spectrum efficient radio access, radio network parameters have to be adapted in an either network-terminal collaborative or autonomous manner with respect to changing customer behaviour in order to offer optimal network performance. A key objective of the flexible and efficient use of spectrum is the provision of broadband access in rural areas.
- **Increase system management efficiency for network operation and (re-) configuration building on cognitive system and distributed self-organisation principles.** Corresponding architectural designs and algorithms will be proposed and assessed, specifically targeting collaborative distributed optimisation of operational parameters as well as fully autonomous functions. Moreover, the efficient provision of context information required for distributed parameterisation is addressed.

3. E³ KEY STUDY AXES

The E³ project organizes the Business, Standardization and Regulation related work as well as the technical effort within six Working Packages (WPs) which are presented in the sequel.

The Working Package on **Business Research, Regulation and Standardization (WP1)** targets contributions to the definition of the global architecture in terms of market, regulation, standardization, business models. Thus, there are two key axes which are first "*Market Opportunities and Business Cases*", and second "*Regulation and Standardization*"; both axes lead to the Project Dissemination and Exploitation plans and to the Standardization and Regulation Strategy (detailed in Chapter 4).

The "*Market and Business*" axis intends to study long term and short term market opportunities and drivers for cognitive systems adoption, identifying key ecosystem stakeholders perceptions and studying specific business cases from different viewpoints (system requirements, service offerings). The studied business cases cover full

range of markets addressed by cognitive wireless systems, in order to give the knowledge on demand and usage pattern, service offerings potential impacts on business models for stakeholders, value chain building. The ecosystem modeling studies are done in conjunction with specific Cognitive Enabler and Radio Enabler business model analysis.

These business studies are closely following the "*regulation and standardization*" axis, as these two items guide the field of allowed and feasible technical solutions and as the relevant responsibility chain concept must be incorporated in these business model studies. In this "*regulation and standardization*" axis, the main focus is on the regulatory framework, the responsibility chain and dynamic spectrum allocation. These aspects are closely related to the actions and contribution towards regulatory bodies and to the study of standardization opportunities within the different Standardization bodies. (IEEE, ETSI,...).

The Working Package dealing with **System Research - Requirements, Features & Architecture (WP2)** has the objective to find architecture for functions that facilitate a higher efficiency of radio systems by performing purposive re-configuration actions in radio terminals and/or radio network elements. We further distinguish between autonomous and collaborative re-configuration actions. A collaborative action is defined as an action that involves more than one network element and/or terminal. An autonomous action is seen as an action that is performed inside one network element or terminal. For the system architecture the necessary additional reference points, interfaces and protocols will be defined. It will be studied how those will fit into existing standards and how to be efficiently prepared for emerging radio systems. The system architecture effects also the inter-actions with network management functions. Emphasis will be put onto a unified entity model that especially facilitates the object identification within the heterogeneous radio system. Furthermore, necessary specification means will be provided, models for programmable interfaces (in a platform independent way) will be proposed corresponding standardization activities will be carried out. These activities rely on the definition of equipment architecture for radio system elements. The work will capitalise on E2R II System Architecture work and provide evolutionary steps from current SOTA.

The work includes:

- Building a unique architectural framework that supports both the Telecom Functions (all system operations that ensure proper communication sessions control) and the O&M Functions (all system operations that ensure proper behaviour of the system elements) in the context of wireless reconfigurable/cognitive systems,

- Specification of the system entities (their continuous identification and capabilities) and the self-x functionalities that will be integrated in the System Architecture,
- Specifying and introducing Cognitive Control Functions in the System Architecture (SA) and its Functional Entities (FE),
- Specification of the interfaces, the interactions and the corresponding signalling protocols for FE interactions,
- Functional model and information set specifications for the basic enablers of cognitive functions: Context retrieval and knowledge management, Cognitive service provisioning, Governance of self-managed, self-organising systems, Cognitive and distributed policy based decision making,
- Definition of standardised formal languages like DSL (Domain Specific Language) and FDL (Functional Description Language) for tool and implementation support.

The Scope of the Working Package on **Collaborative Cognitive RRM, Spectrum Management and Self-Organisation (WP3)** is to provide and evaluate measures and algorithms to increase performance and efficiency of future heterogeneous radio communication systems. This will enable advanced flexible utilisation of scarce radio resources like e.g. frequency spectrum, power, etc. as well as reduced effort in terms of capital investment and operational expenses by means of collaborating cognitive and self-organising user equipment and access network elements. Assessment of effectiveness and efficiency of selected concepts built up by properly combined sets of algorithms following a dedicated strategy will be achieved by simulation frameworks accounting for current and expected future real-world environments. The Working Package covers definition and analysis of functionalities, algorithms and processes to enable collaborative resource, spectrum and system management, self-organisation and -optimisation, semi-distributed cognition and decision-making and an overall simulative assessment of these techniques and concepts with respect to E³ system architecture in terms of an efficient end-to-end performance from both an end user and an operators point of view. Approaches to be investigated cover the topics of newly developed and enhanced algorithms for RRM and DSA, procedures and protocols to enable cognition and adaptability within radio networks, management functionalities for network control and resource allocation within wireless systems, different degrees of distribution for decision-making, automated and self-x (x = planning, configuration, optimisation, healing, etc.) assisted operation of access network nodes as well as self-organisation of collaborating nodes and subnetworks, and overall network

aspects. The work of WP3 is defined to include a complete cycle from requirements engineering, modelling, simulating and evaluating to verification of the approaches and algorithms, concluding in recommendations for service and network providers as well as equipment manufacturers.

RRM, DSA and collaborative self-x operations will be described for terminals and base stations, required interfaces, reference points and information exchange between those nodes and dedicated control entities (e.g. Spectrum/Access Brokers) will be identified, and a simulation-based assessment of the algorithms will provide basis for further development, combination and implementation.

Investigations focused on collaborative aspects in RRM including DSA and self-x concepts will perform an assessment of procedures and metrics for optimised resource usage in single- and multi-RAT (Radio Access Technology) environments with semi-distributed optimisation mechanisms. The impact of E³ cooperative RRM/DSA optimisation and self-organising algorithms on existing (e.g. HSPA), upcoming (e.g. 3G-LTE) and future (e.g. IMT-Advanced) systems will be described.

Whereas WP3 studies collaborative operation between RAN/RAT domains allowing evolutionary approach, the Working Package WP4 deals with **Autonomous functionalities & algorithms in a Cognitive Radio/Network Context** and develops a disruptive fully distributed future concept for Cognitive Radio that does not require any additional network elements, such as Spectrum Brokers. Such alternative concept relies on collaborative operation between radio nodes, regardless on which RAT/RAN (if any) they are using or belong to. In scenarios where decisions related to Cognitive Radio operations are limited only to the radio nodes (mobile devices or access points/base stations), either such nodes must make completely autonomous decisions based on information received from the surrounding nodes or the decisions are made jointly in a collaborative fashion. This leads to very dynamic and opportunistic use of the spectrum without the need to introduce CR functionality in any other than the radio nodes. Additionally advantage is that the need to agree on multiple interfaces between various higher layer network nodes of different RATs is avoided. Basing the cognitive radio concept on such flat structure of CR nodes without any hierarchy (no central node above making decisions for you) requires pushing the envelope of the cognitive radio research into areas such as artificial intelligence, machine learning and dynamic distributed systems. The primary objectives of WP4 are: 1) to develop innovative system-level schemes for autonomous operation (operation not relying on central control entities); 2) to push the envelope of E³ by developing solutions based on the newest results from dynamic distributed systems and machine learning.; 3) to understand

the pros and cons of autonomous solutions with respect to the solutions relying on overlay control structures; 4) to assess the performance and complexity of the developed solutions; 5) to make empirical feasibility validations of the autonomous functions and schemes.

The scope the Working Package on **Support for Heterogeneous Standards (WP5)** is focused on the key items in the context of heterogeneous wireless systems, targeting the efficient interworking of multiple distinct standards taking into account both the overall system perspective and the equipment functionalities. The work of WP5 is defined to design and engineer the signalling and protocols for the Cognitive Pilot Channel (CPC) considering both the In-band (i.e. the pilot channel consists in a channel inside an existing bandwidth/system like 2G, 3G or WiMAX allocated for the CPC purpose) and Out-band (i.e. the pilot channel consists in a dedicated global or local channel) solutions. As an example, the work on CPC comprises the mesh dimensioning (a mesh is the single element of the area in which heterogeneous standards are present) taking into account the trade-off between physical constraints resolution (i.e. what is the suitable size to differentiate different space/time interference conditions) and the associated signalling overhead (the amount of necessary information and required channel bandwidth will be evaluated). In addition, the WP5 is also focusing on the transport/physical aspects (frequency/time/code, bandwidth, transmitted power and uplink and downlink handshakes) related to the introduction of CPC and to the coexistence of heterogeneous standards, identifying key elements for multiple active standards guaranteeing an efficient interworking, considering also emerging standardization activities, such as IMT-advanced. Moreover, the WP5 framework foresees also the design of Information Provision mechanisms for supporting terminals, network elements, and respective management entities in a cognitive network context are addressed. This work is focused on the design of detailed data and frame structures, definition of the related procedures and protocols, and the further mapping on out-band and/or in-band, legacy and new physical channels. Performance evaluation (using analytical models and/or system-level simulations) of the designed protocols are also addressed considering legacy system such as for example UMTS evolutions (e.g. HSDPA) or the CPC itself as bearers.

Finally, the Working Package WP6 deals with **Prototyping**. In this framework, the E³ prototyping platform is developed which will allow implementing and validating concepts developed in other WPs. This platform is needed to integrate the building blocks of the cognitive systems that E³ will introduce in the B3G world. As a second objective, the WP6 aims at implementing a process (consisting of scenarios, use

cases, interfaces, integration and demonstration/validation) that will enable the integration and validation of functionality for RRM and DSA in a cognitive context, and for cognitive/autonomic elements (cognitive and self-x functionalities, protocol stacks). The platform will allow to demonstrate a wide variety of scenarios from simple ones (using one of the current widely spread RATs) to more complicated ones (using multi-homed or SDR devices acting in a heterogeneous multi-domain environment where spectrum trading and base station reconfiguration can occur).

All the design and implementation activities involved in these objectives will be tightly linked to the overall standardisation activities especially concerning the necessary interfaces that network elements and terminals should have in a cognitive context.

The platform will provide the means for experimenting with complex, heterogeneous B3G infrastructures (e.g. 2G/3G/4G mobile, IEEE 802.x, WiMAX, Multi-Standard and Multi-Band Base Stations (MSBS) or SDR equipment) comprising network elements and terminals, which are available in hardware or simulated/emulated in software. The models of simulated/emulated elements will include the element's behaviour and the potential features of its environment, in terms of traffic/mobility/interference etc.

The effort within E³ will finally lead to an exploitation on the following three axes: i) Commercial Exploitation, ii) Regulation and iii) Standardization.

4. E³ STANDARDIZATION AND REGULATION STRATEGY

It is an essential element of the E³ strategy to influence most relevant standardisation and regulation bodies by impacting with E³ consortium proposals. In this context, the intention is to concentrate on standards with a focus on Cognitive Radio/Networks and Architecture aspects as well as Convergence and Interworking of Heterogeneous Wireless Systems. Further standards have been identified that will be monitored closely. It is also a stated goal of E³ not to focus on standards of a single region only, but to ensure the coverage of the most relevant standardisation bodies across the globe, in particular ETSI and IEEE.

In this context, E³ intends to pursue two strategic paths: i) E³ will push the evolution of next generation cognitive radio and network standards by providing technical inputs targeting more efficient and reliable functionalities and services; ii) with the objective of ensuring the convergence of multiple standards, E³ will identify critical elements of next generation standards (e.g., in the framework of IMT-Advanced) which are essential for an efficient coexistence

and interworking of various standards (i.e., cellular, metropolitan area and short-range standards). E³ is going to contribute to selected elements ensuring thus the efficiency of future heterogeneous wireless cognitive systems.

Figure 2 is illustrating the key standards and regulatory bodies which have been identified by the E³ consortium. On the horizontal axis, the respective landing zones have been split into distinct focus areas, while the vertical axis indicates the current maturity of the standardisation processes: i) “Future Creation Expected” indicates that a relevant standardisation group is expected to be created in a short- to mid-term perspective; a typical example is here a future Cognitive Systems effort in ETSI; ii) “In Progress” indicates that the current group is active and iii) “(Almost) finalised” standards are of limited interest, since no relevant inputs are likely to be accepted.

Beyond the E³ coverage scope for contribution (yellow boxes), Figure 2 also illustrates that some novel existing standards will be of relevance to application in the prototyping framework; this is in particular the case for the SCTP (Stream Control Transport Protocol) protocol which will enable E³ to efficiently develop a demonstration platform where a data stream is split over multiple air interfaces.

While the E²R programme has opened the grounds to feed findings and concepts from E³ into the regulatory discussions and to directly influence regulation, specific exploitation steps are:

- E³ will introduce the concepts for certification of cognitive enabled equipment and distributed decision-making oriented systems into future evolutions of the R&TTE Directive.
- E³ will further the "Responsibility Chain" concept and will feed the concepts into the ECC working group (WG RA – Regulatory Affairs)
- Information about and proposals how Dynamic Spectrum Access may impact service providers and network operators will be fed into WG-FM – Frequency

Management and WG-SE – Spectrum Engineering, respectively.

- E³ will propose solutions and enablers for dynamic spectrum access, and provide contributions to relevant regulatory bodies (ECC, ITU-R, etc.).

5. CONCLUSIONS

The FP7 Integrating Research Project proposal E³ was presented and detailed, starting with the vision of a heterogeneous wireless network approach designed for a smooth evolution from existing Radio Access Technologies towards novel standards, such as the ones building the framework of IMT-Advanced. Furthermore, the key study axes have been outlined; finally, an overview of the current standardization and regulation landscape is given and it has been shown that E³ plans to actively contribute to the standards relevant for the convergence of future wireless systems.

6. ACKNOWLEDGMENT

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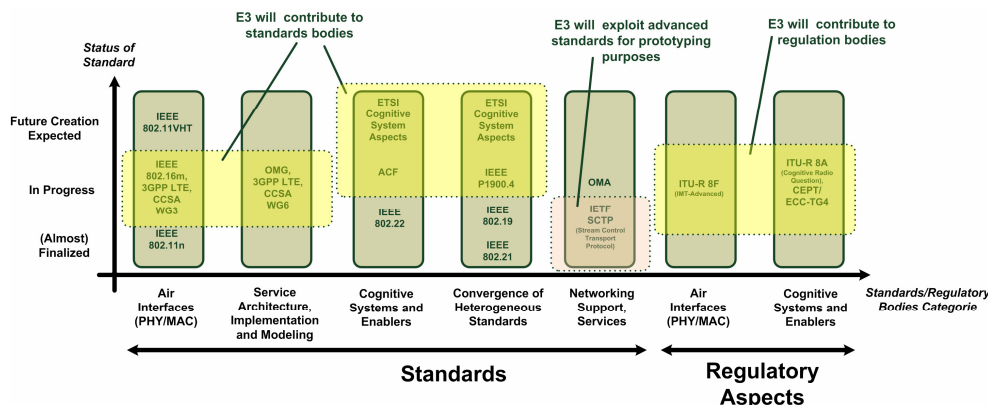


Figure 2: E³ Standardization Strategy.